# Low Load Operation at the Killen Generating Station

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***Abstract*—As coal generation continues to experience economic and environmental pressures in the United States, flexibility is likely to be critical to a utility's ability to avoid cycling units in and out of service weekly or even nightly. In an effort to be proactive in preparing for these possibilities, Dayton Power & Light's Killen Station is making efforts to add operational flexibility and lower low load generation costs with the intent of maintaining an economic advantage. The Killen Station has a single 650 MWg subcritical unit. The unit is scrubbed, has selective catalytic reactors and presently burns lower cost, high sulfur coals predominately from the Illinois Basin. Historically, the minimum load without support fuel has been 230 MWg. Low cost modifications to the combustion system have been made and tested to demonstrate the ability to safely operate down to 180 MWg without fuel oil in support of the coal fires.**

***Key Words* — Flame stability**
**Minimum load**
**Partial pulverizer firing**

## I. Nomenclature

B&W – Babcock & Wilcox
FPS – Fossil Power Systems
Dark Spread- Difference between the price received by the generator and the cost of the coal needed to produce that electricity.
DP&L – Dayton Power & Light
DRB-4Z – Dual register burner, style 4Z
gpm- gallons per minute
MCR – Maximum continuous rating
MPS – Vertical mill type
MWg – Gross generation in megawatts
MWH – The equivalent of a megawatt of generation for one hour duration.
NFPA – National Fire Protection Association
NOx – Compounds of nitrogen oxides
PC – Pulverized coal
PJM –PJM is a regional transmission organization (RTO) that coordinates the movement of wholesale electricity in all or parts of 13 states and the District of Columbia.
TPH- tons per hour

## II. Introduction

Power pricing in the PJM power pool varies significantly with demand. The historical and projected dark spread is low during the off peak periods (Figure 1), making it difficult to make profit during some off peak times. In 2012, the real time local marginal price in the PJM Dayton zone ranged from minus $122.38/MWH to plus $797.78/MWH. A negative price indicates the cost power producers can be forced to pay to put their power on the grid during off peak periods. These power prices are usually low for a short period of time (1-8 hours). Due to start up and shut down costs and equipment stress, it is not desirable to remove a unit from service.

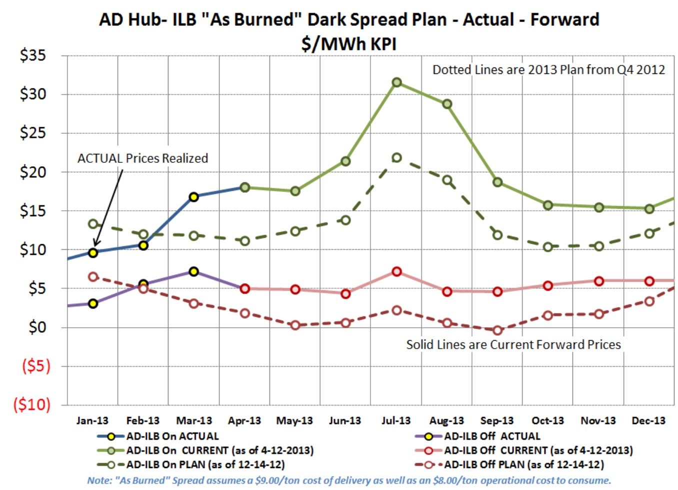


Fig. 1. Dark Spread Pricing

On large coal fired units, there are a number of constraints that determine minimum load. This paper describes an innovative procedure that improved Killen Station's ability to achieve lower minimum loads.

## III. Historical Minimum Load

The DP&L Killen Unit 2 boiler is a B&W 650 MWg Carolina-type radiant boiler with a balanced draft furnace. Seven MPS-89N pulverizers supply a total of 49 coal burners with 28 in the front wall and 21 in the rear wall. Front wall, rows 1, 2 and 5 and rear wall row 5 are fed by single pulverizers, with seven burners/row. A single pulverizer feeds rows 3 and 4 on the front wall with a staggered four over three burner arrangement (Figure 2).On the rear wall, rows 1 and 2 and rows 3 and 4 are fired by two pulverizers on staggered three over four burner arrangements (Figure 3). In Figures 2 and 3 letters designate the pulverizer and the number indicate the coal pipe.

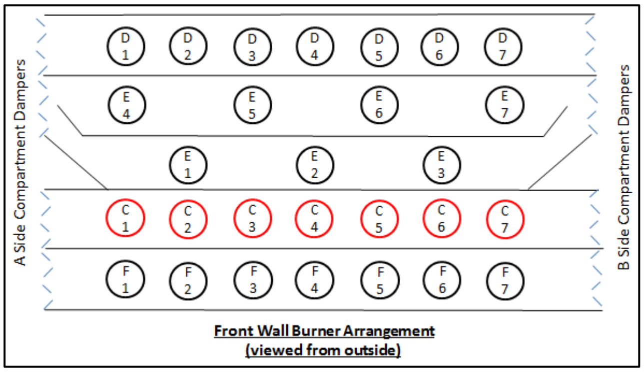


Fig. 2. Front wall burner configuration

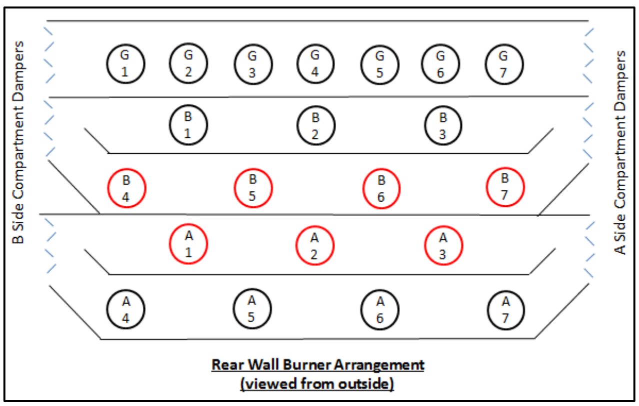


Fig. 3. Rear wall burner configuration

The coal burners were replaced with B&W DRB-4Z PC Low NOx burners in 2008. Each burner is equipped with an FPS oil-fired igniter, for the purposes of pulverizer start-up, shut down, and as necessary for flame stabilization. Each burner is also equipped with an optical flame detector for monitoring the main coal flame quality. Following the installation of these burners testing determined that the minimum load required to maintain a stable coal flame without oil burn was 230 MWg, approximately 35% maximum continuous rating (MCR).

## IV. Estimated Economic Benefits

To estimate how much money could be saved by providing a lower minimum load to PJM, the station assumed it could reduce its current minimum load by 50 MW. This lower constraint was put into the DP&L power plant economic dispatch models, which factor in economic dispatch and projected market pricing. The outcome of this model projected a total net savings of $3.2 million in years 2014-17 (Figure 4). With this information, it was decided to find an economic way to reduce load by at least 50 MW.

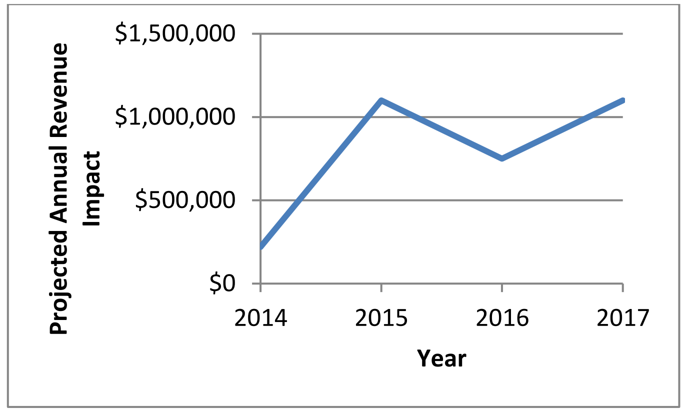


Fig. 4. Projected Revenue Change due to lower load operational capability

## V. Review of System Constraints

Each major system on the unit was reviewed for potential impact of a 50 MW decrease in minimum load. A fish bone diagram was developed in which equipment and potential causes could be readily identified. Sixteen items were flagged as potential problems for which solutions and recommendations were formed (Figures 5 and 6). From this analysis it was determined that after flame stability was addressed no other items would prevent the unit from reaching minimum load. Several other parameters were identified to be monitored once the new minimum load was achieved.

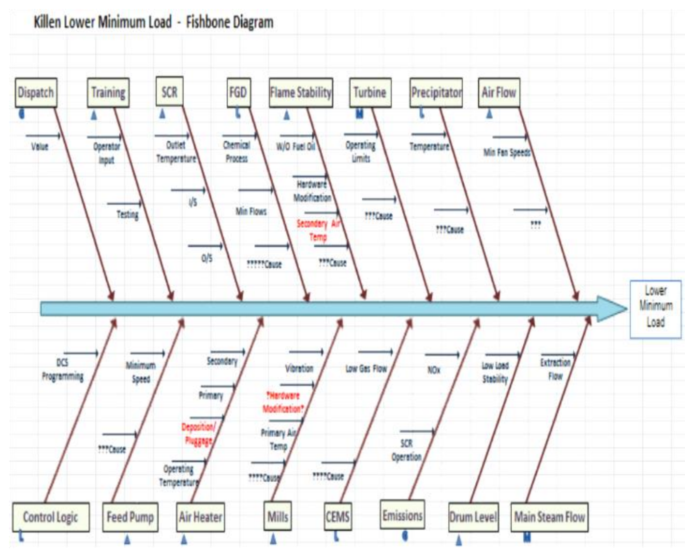


Fig. 5. Low Load Fishbone Diagram

| Area / Equipment | SCR |
|---|---|
| Define Potential Problem / Current State | The SCR has minimum operating temperature that needs to be maintained to prevent ammonium bisulfate accumulation. Unit can be operated below this minimum temperature by by-passing SCR. Need to monitor total tons NOx emitted/12 months. |
| Root Cause / Influencing Factors | Higher NOx emissions results from operation with SCR by-passed. |
| Possible Solution | Operate with SCR, only by-pass as economic market conditions dictate. |
| Recommendation | Track total NOx tons per 12 months; operate at lower min load when economically justified. |

Fig. 6. Typical Potential Problem-Recommendation

## VI. Flame Stabilization & Pulverizer Minimum Throughput

The plant's historical operation has been to insert oil igniters to stabilize the coal flame when load drops below 230 MWg. Doing this is very expensive because each igniter injects 1.5 gpm, which cost approximately $6,700/hour in oil at minimum load.

Minimum load without fuel oil support requires that a minimum of 3 pulverizers be in service. This allows for the ability to lose a pulverizer from service, restore firing rates and maintain load with the remaining two pulverizers while also adding oil. In order to optimize flame stability at low loads it is desirable to consolidate the firing pattern or burner selection.

The minimum pulverizer throughputs at Killen plant has been 24.7 tons per hour (TPH) or 40% of rated capacity. This is based upon maintaining minimum burner line velocities and adequate mean coal particle spatial criteria for flame propagation. In order for the plant to achieve the 180 MWg minimum load goal without oil, it was necessary to alter the combustion process to allow for added pulverizer turndown while still maintaining sufficient burner line velocities.

To resolve the flame stability and pulverizer turndown, it was determined that the A and B pulverizers could be partially fired, using the upper 3 burners for the A pulverizer and the lower 4 burners for the B pulverizer (shown in red in Figure 3). The remaining burners associated with these two pulverizers would need to be positively isolated, consistent with NFPA guidelines. By making these operational adjustments to these two pulverizers, the sum of the burners remaining in service would simulate the firing rate of a single pulverizer in regards to minimum throughputs. In order to still have three pulverizers in service and an optimally condensed firing pattern, the C pulverizer would be used in conjunction with the partial firing of the A and B pulverizers, confining the new minimum load firing to rows 2 and 3. Reference Figures 2 and 3 burners highlighted in red.

## VII. Preliminary Testing

In order to initially establish the ability to partially fire a pulverizer and the necessary adjustments to primary and secondary air coordination with the turndown capability, the E mill was selected for testing[1] with the three lower burner lines blanked. This preliminary testing was performed at a load of 280 MWg with 3 additional lower pulverizers in service to simulate a reasonable separation and flame stability challenge.

It was found that the E pulverizer, operating with three burners in service could be effectively turned down to 20% of rated flow or 12.3 TPH. The pulverizer experience no problems with coal dribble through the pyrite collection. Nor was the vibration with the lightly loaded pulverizer excessive.

From the initial testing, new coordination curves for both primary and secondary air were developed for a true low load test with the A, B and C pulverizers in service.

## VIII. Unit Modifications

Pneumatic operated zero leakage isolation gates have been installed in the A4-A7 and B1-B3 burner lines. These gates allow these burner lines to be readily isolated remotely from the control room after an initial purge of the pulverizer and burner lines before returning the pulverizer to service. The remaining firing groups already had separation in the oil lighter valving and controls, allowing for the oil lighters on only the fired burners to be utilized.

Logic changes were required to allow the partial pulverizer firing to keep swing valves on the isolated burner lines to stay closed while allowing primary air flow and the pulverizer and coal feeder to be started. In the final operational logic, the firing master will automatically proportionately divide the demand to the in service pulverizers by the number of burners in service. For all of the testing to date, this function was performed with the partially fired pulverizers in manual. However, primary and secondary air coordination was automated.

## IX. Low load testing

The Killen Unit was reduced in load to 180 MWg with partial firing on the A and B pulverizer and near the equivalent combined firing rate from the C pulverizer without oil firing. This condition was maintained for 6 hours without incident. The duration was selected with the intent of assuring that parameters that effect flame stability were allowed to normalize. These parameters included available hot primary air and secondary air temperatures and the ability to maintain pulverizer outlet air/fuel temperatures. The unit operation was able to take advantage of the existing economizer bypass dampers and flues to increase gas temperatures to the tubular

[1]The E pulverizer was selected for preliminary testing versus the A or B pulverizer solely upon its limited impact on plant operation while physically isolating burner lines during normal unit operation.

primary air heater and the regenerative secondary air heaters.

The hot primary and secondary combustion air temperatures required about 2¾ hours to normalize. In comparison to full load operating temperatures, the hot primary air dropped from about 480 to 430 degrees F, allowing the pulverizer air/fuel temperature set point of 170 degrees F to be maintained for the A and B pulverizers. However, the C pulverizer outlet air/fuel decayed to between 140 and 145 degrees F. The secondary combustion air temperature dropped from about 490 degrees F at full load to 410 degrees at 180 MWg.
Control limitations were encountered due to a failed A pulverizer burner compartment damper drive and an apparent leak in the high side of one of the A pulverizer compartment flow transmitters. This necessitated that the two A pulverizer burner compartment inlet dampers be manually positioned, limiting the ability to accurately coordinate secondary air and pulverizer throughput. This produced some visual shifting of the flame fronts further from the burner throats, but the flames remained stable. Note that the loss of flame indication from 2 of the in service burners from the A or B pulverizers would have initiated a pulverizer trip. There was no indication of loss of flame from any burners (visually and per the flame scanners) throughout the 6 hour test duration.

Indicated average flame intensities as measured with the optical flame scanners decayed approximately 5-6% on the A and B pulverizer burners that were in service while transitioning from near full load to 180 MWg and approximately 10% on the C pulverizer burners during the same load transition (Figure 7).

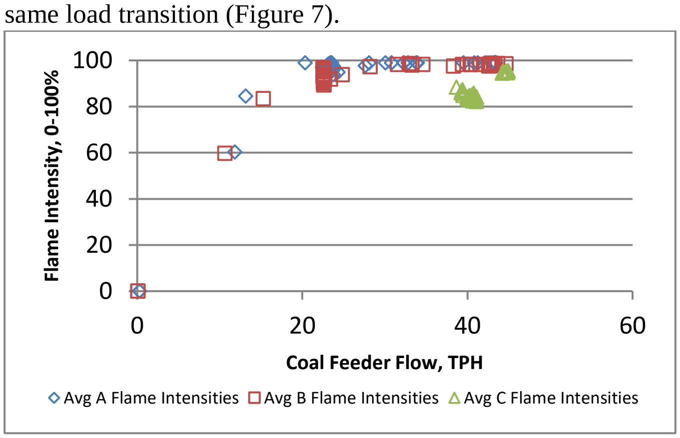


Fig. 7. Average flame intensities measured for A, B and C pulverizer burners in service from full load to 180 MWg.

The A and B pulverizer fineness was tested during the minimum load test for reference. The results are presented in the Rosin-Rammler charts presented in Figure 8. A typical fineness level for Killen pulverizers operating at full load conditions or near 40 TPH is also illustrated for reference. As expected the fineness improves at the lower pulverizer throughput.

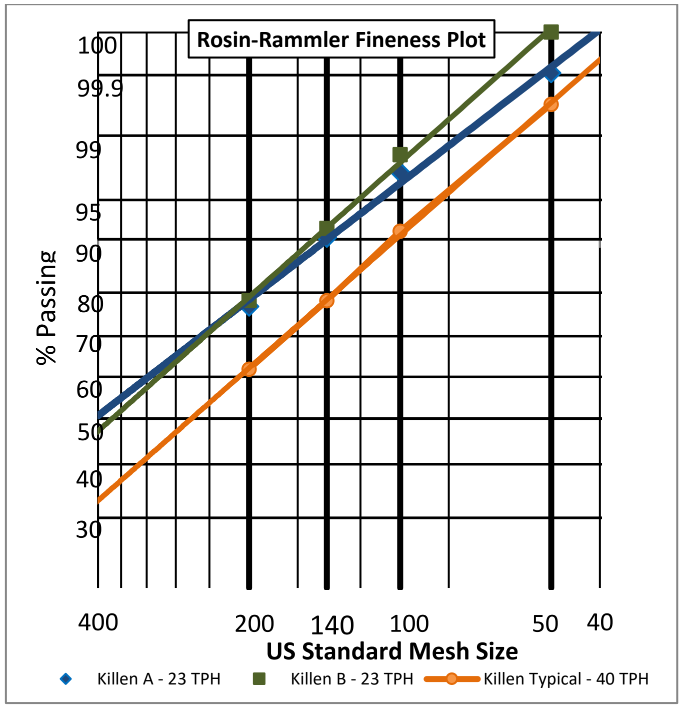


Fig. 8. Fineness Results from A and B Pulverizers

## X. Remaining Concerns and Proposed Adjustments

During the 6 hour test at 180 MWg, the average cold end temperature decayed to 180 degrees F. Although the increase in excess air dilutes the condensable acids in the combustion gases, there is some concern that extended low load operation could contribute to additional cold side gas flue deterioration, particularly downstream of the secondary air heaters.

If commercially taken advantage of, the lower minimum load operation without oil would be further optimized to operate the in service burners at a stoichiometric combustion air ratio of near 1.0 in order to approach adiabatic flame temperatures and further strengthen flame stabilities.
Note that the partial pulverizer firing capability has additional benefits during unit startup to limit step increases in firing rates.

## XI. References

*Books:*

[1] The Babcock & Wilcox Company, *Steam/ its generation and use*, 40th edition.

*Technical Reports:*

[2] Babcock & Wilcox Customer Training, "MPS Pulverizer Operations Manual”

## XII. AUTHORS, BIOS AND PHOTOS

**Scott Vierstra, P.E.** graduated with B.S. degrees in Mechanical Engineering and Life Sciences from the Massachusetts Institute of Technology. He has been working in the utility industry for 32 years, the last 14 years as the principal of SAVvy Engineering LLC. Prior to 1999, he was employed at American Electric Power in their Steam Generation Engineering Group. He has several patents involving low NOx combustion systems and patents pending in pulverizer classifier developments and calcium carbide production in coal fired steam generators

**Michael Harrell, P.E.** graduated with a B.S. degree in Mechanical Engineering from the University of Dayton, and with a MBA degree from Xavier University. Over the last 25 years he has held a variety of positions in the Engineering, Operations and Maintenance Departments in coal fired power plants. Currently he is the Director, Engineering and Construction for Dayton Power & Light's Power Production Division.